NeoBiota 76: 191–210 (2022)
doi: 10.3897/neobiota.76.77944
https://neobiota.pensoft.net

DISCUSSION PAPER

A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

Expanding the invasion toolbox: including stable isotope analysis in risk assessment

Paride Balzani[1,2], Phillip J. Haubrock[2,3]

1 *Department of Biology, University of Florence, Via Madonna del Piano 6, 50019 Florence, Italy* **2** *University of South Bohemia in České Budějovice, Faculty of Fisheries and Protection of Waters, South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses, Zátiší 728/II, 389 25 Vodňany, Czech Republic* **3** *Senckenberg Research Institute and Natural History Museum Frankfurt, Department of River Ecology and Conservation, Clamecystrasse 12, 63571 Gelnhausen, Germany*

Corresponding author: Paride Balzani (paride.balzani@unifi.it)

Academic editor: Marina Piria | Received 12 November 2021 | Accepted 13 January 2022 | Published 3 October 2022

Citation: Balzani P, Haubrock PJ (2022) Expanding the invasion toolbox: including stable isotope analysis in risk assessment. In: Giannetto D, Piria M, Tarkan AS, Zięba G (Eds) Recent advancements in the risk screening of freshwater and terrestrial non-native species. NeoBiota 76: 191–210. https://doi.org/10.3897/neobiota.76.77944

Abstract

Species introductions are a major concern for ecosystem functioning, socio-economic wealth, and human well-being. Preventing introductions proved to be the most effective management strategy, and various tools such as species distribution models and risk assessment protocols have been developed or applied to this purpose. These approaches use information on a species to predict its potential invasiveness and impact in the case of its introduction into a new area. At the same time, much biodiversity has been lost due to multiple drivers. Ways to determine the potential for successful reintroductions of once native but now extinct species as well as assisted migrations are yet missing. Stable isotope analyses are commonly used to reconstruct a species' feeding ecology and trophic interactions within communities. Recently, this method has been used to predict potentially arising trophic interactions in the absence of the target species. Here we propose the implementation of stable isotope analysis as an approach for assessment schemes to increase the accuracy in predicting invader impacts as well as the success of reintroductions and assisted migrations. We review and discuss possibilities and limitations of this methods usage, suggesting promising and useful applications for scientists and managers.

Keywords

Impacts, mixing models, modelling, prediction, screening, stable isotope analysis

Copyright *Paride Balzani & Phillip J. Haubrock.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Introduction

Species introductions are an increasing concern for global biodiversity conservation (Doherty et al. 2016; Ricciardi et al. 2017; Bradley et al. 2019). This includes foremost the introduction of alien species, i.e. those species accidentally or intentionally moved outside their natural geographic range by humans, which shows no sign of saturation (Seebens et al. 2017). Introduced species often interact (Veselý et al. 2021), in many cases facilitating each other's establishment (Simberloff and Von Holle 1999), increasing their impacts due to interactions with anthropogenic stressors such as pollution (Crooks et al. 2011) and climate change (Hellmann et al. 2008; Rahel and Holden 2008; Beaury et al. 2020) and thereby become invasive. In addition to impacts on ecosystems (Ehrenfeld 2010), negative effects on human health (Mazza and Tricarico 2018) and ecosystem services (Walsh et al. 2016), as well as increasing economic costs due to direct damages (Ahmed et al. 2021a, b; Angulo et al. 2021) and associated management (Bradshaw et al. 2016; Diagne et al. 2021) are increasingly recognized.

To be effective, efforts to control invasive species should follow the hierarchical approach of the 2002 Convention on Biological Diversity, with prevention as the best option (Simberloff et al. 2013; Roy et al. 2019). For this purpose, risk screenings that identify which species should undergo a comprehensive risk assessment as well as standardized risk assessment protocols to identify potentially arising new threats have been developed (Essl et al. 2011; Vilizzi et al. 2021). These primarily aim at the identification of the most harmful species, pathways, and susceptible (invadable) sites whose protection should be prioritized (McGeoch et al. 2016). Risk assessments are usually designed for specific taxonomic groups (Copp et al. 2009; Brunel et al. 2010), vectors (Gollasch and Leppäkoski 2007), ecosystems (Leidenberger et al. 2015), or geographic regions (Baker et al. 2008), although more comprehensive protocols have been proposed (Copp et al 2016; Davidson et al. 2017). Overall, these protocols attribute a total score summing the separate scores of assessments of species traits, ecological impacts, distribution, and control feasibility, for each of which an uncertainty level is provided (Dahlstrom et al. 2011; Srėbalienė et al. 2019).

Together with predictive models, which use the ecological niche of an invasive species to probabilistically predict its future invaded range (Mainali et al. 2015; Uden et al. 2015), risk assessments are the main tools used to inform decision-makers and wildlife managers and provide fundamental information for legislations that prevent further invasions (Fournier et al. 2019), also in the context of future climate change scenarios (Chai et al. 2016). More recently, risk assessments and species distribution models have been used in combination, increasing the realism and accuracy of the predictions (Chapman et al. 2019; Yoğurtçuoğlu et al. 2021). Alternative taxa-specific approaches are trait-based models that scan a species list using ecological traits from known invasive species to identify potential new invaders (Howeth et al. 2016; Fournier et al. 2019). However, information is often missing, scarce, or anecdotal, particularly on impacts, leading to the assignment of "no potential impact" (Davidson and Hewitt 2014; Davidson et al. 2017) or "data deficient" (Kumschick et al. 2020).

On the other hand, species reintroductions, i.e. the translocation of individuals to areas in which a species became extinct with the aim of re-establishing a self-sustaining population, are of considerable value for conservation efforts (Haase and Pilotto 2019) but rarely successful – mostly due to life-cycle complexity or unpredictable external stressors (abiotic stress; biotic stress such as competition and predation; for a detailed account see Jourdan et al. 2019). Indeed, following the local extinction of a species, multiple factors can inhibit the occurrence of natural recolonization (Kail et al. 2012). For this reason, habitat restoration projects are often undertaken (Loch et al. 2020), although they too may fail due to various unforeseen factors (Bond and Lake 2003; Roni et al. 2018). Nevertheless, reintroductions are commonly used as a tool for wildlife rehabilitation (Armstrong and Seddon 2008), while the effectiveness of such reintroduction attempts themselves will depend on several intrinsic and extrinsic factors (Jourdan et al. 2019). Particularly, the interactions with other unwanted co-occurring species (i.e. alien species) can lead to failure of the reintroduction efforts (Cochran-Biederman et al. 2015).

Similar hurdles are faced by new conservation methods that have been proposed, like assisted migrations, i.e. the translocation of individuals to areas where they are predicted to move according to climate change but are not able to do so naturally (Hällfors et al. 2017). Some threatened species that could naturally move into new areas in accordance with their environmental and ecological requirements are inhibited to do so by limited time or human disturbances. For example, the presence of artificial barriers to natural dispersion can impede the ability of a species to respond to climate change and maintain its populations (Schwartz et al. 2012). Assisted migrations allow individuals to overstep such barriers in reasonable times to aid the species avoiding extinction (Schwartz et al. 2012). Although this approach has already been used (Willis et al. 2009), its application is still largely debated (Pérez et al. 2012; Schwartz et al. 2012) and depends on a trade-off between costs and benefits (Hoegh-Guldberg et al. 2008). For example, assisted migrations may lead to conservation paradoxes of species considered as endangered in their native range but recognized as invasive in their introduced range (Marchetti and Engstrom 2016; Marková et al. 2020). Accordingly, other criteria like feasibility of the translocation and collateral impacts (including the arising biotic interactions) need to be considered (Richardson et al. 2009; Hällfors et al. 2017). Therefore, the implementation of biotic outcomes prediction is crucial to assess whether assisted migration is an advantageous conservation strategy (Peterson and Bode 2021).

In all these cases – ranging from biological invasions to conservation biology – the arising biotic interactions, such as trophic relationships, are difficult to predict, while representing a crucial point for effective forecasting. In particular, what is still lacking is a fine-scale prediction of potential trophic impacts (in terms of predation and competition) on the recipient community and trophic pressures that focal species will encounter. Here we propose the use of stable isotope analysis as a tool for assessment schemes to predict such trophic relationships, and discuss the requirements, advantages, and assumptions of such an approach.

Stable isotope analysis (SIA)

General description

Stable isotope analysis (SIA) of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) can reveal long-term and time-mediated information of a community's trophic structure and connectance (Boecklen et al. 2011; Layman et al. 2012; Middelburg 2014). Moreover, SIA can be used to quantify ecological niches, reveal trophic interactions as well as feeding preferences (Kelly 2000; Newsome et al. 2007), and enable the estimation of trophic levels (Post 2002; Quezada-Romegialli et al. 2018). Carbon signatures relate to the major energy sources, while nitrogen to the trophic position of a consumer within a food web (Fry 2006; Layman et al. 2012) due to predictable changes in the isotopic signal from prey to consumer, being enriched by 1‰ for carbon and by 2.5–5‰ for nitrogen between consecutive trophic levels (Post 2002; Vanderklift and Ponsard 2003). Using mixing models, it is also possible to determine the contributions of different prey items to the diet of a consumer (Phillips et al. 2014), with the possibility of including literature-based information or diet analysis data as priors to increase the analysis accuracy (Parnell et al. 2013).

Stable isotope analysis has been proven to be a useful tool in the field of invasion ecology (Vander Zanden et al. 1999). It is often used to assess the impacts of introduced species on other taxa in term of predation (Haubrock et al. 2019a; Gaiotto et al. 2020; Oe et al. 2020) and competition with native (Balzani et al. 2016) and other alien species (Balzani et al. 2020; Haubrock et al. 2020a). Moreover, it can be used to reveal the role of new alien prey in the diet of resident predators (Juarez-Sanchez et al. 2019; Stellati et al. 2019), compare trophic levels between introduced and native populations of invasive species (Balzani et al. 2021), as well as to disentangle trophic relationships among alien species in invaded communities (Haubrock et al. 2019a; Bissattini et al. 2021). Finally, SIA can be used to identify links between terrestrial and aquatic environments and depict changes in either one following alterations in the other (Gregs et al. 2014). However, the potential of SIA in this research field has not been fully explored yet (Bodey et al. 2011), and new applications have recently been suggested (McCue et al. 2020).

Predicting biotic interactions

Recently, SIA and associated mixing models have been proposed as a new and versatile approach in assessing potential risks arising from feeding pressure by invasive species, thus enabling to forecast the possible outcomes of the reintroduction of once native species (Haubrock et al. 2019b) and unravelling the role of species introductions on native species extinction (Haubrock et al. 2020b).

These seminal studies were carried out in an aquatic system, namely the model community of Lake Arreo, Northern Spain, which is currently dominated by alien species (Haubrock et al. 2018). In the first study (Haubroch et al. 2019b), the isotopic

niche of the European eel *Anguilla anguilla* from a German lake with a similar community composition (Dörner et al. 2009) was projected onto the isotopic community structure of Lake Arreo, where this fish species was once native. The aim was to assess the effectiveness of this predator as biocontrol agent for the aquatic alien species. To allow comparisons, data from both eel and the Arreo community were standardized using the baseline organism (primary producer, *Phragmites australis*) that occurs in both ecosystems. In the other study (Haubrock et al. 2020b), isotopic data from a vertebrate (the common tench *Tinca tinca*) and one invertebrate (a whirligig beetle *Gyrinus* sp.) species once native but now locally extinct, were extrapolated from suitable literature and projected in the community to model biological effects (predation, competition) that potentially lead to their demise.

As such, these studies determined a considerable biotic pressure, mostly driven by both predation from the occurring (introduced) top predator, the largemouth bass *Micropterus salmoides*, and competition with native and other introduced species. Furthermore, the potentially arising trophic web was conceptually depicted considering the potentially consumed prey of the reintroduced eel, and thus, its effect on the recipient community. These studies thereby highlighted the opportunity for a new research line that exploits the potential of isotopic data to assess specific impacts at local scales. For example, the analysis of isotopic niches and resource utilization can be used to predict interspecific interactions (i.e. either competition or predation) after the potential introduction of a global invader in other areas or locations.

Here, we propose the application of this approach as a tool to use within risk analysis frameworks, including horizon scanning and risk screening and further assessments, to prevent new invasions, and to optimize reintroduction as well as assisted migration efforts by assessing the probable trophic relationships arising. Therefore, we discuss the requirements, advantages, and assumptions of this application.

SIA impact assessment

Requirements

Trophic links between species are the result of specific local conditions, as for example the number of trophic levels and the biomass within each – and, thus, prey availability and competition – depend on the productivity of ecosystems (Leibold et al. 1997). Each community differs and is unique due to various factors such as species composition and abundance, behavioural differences and local adaptations, different energy pathways as well as connectance with the surrounding ecosystems, and ultimately abiotic variables (e.g. substrate, altitude, climate). Although consumers show a certain degree of behavioural and dietary plasticity (Lehmann et al. 2013; Svanbäck et al. 2015; Mavraki et al. 2020), it can be assumed that under similar abiotic conditions, communities with similar species would reflect similar trophic positions and structures (Haubrock et al. 2020b). Therefore, it is important to accurately choose

data from communities as similar as possible to the focal community (Haubrock et al. 2019b). Moreover, the standardization of isotopic data using local baselines (i.e. primary producers or, preferably, primary consumers) is needed to make data comparable (McMahon and McCarthy 2016). However, the two data sources should rely on the same energy pathway (i.e. terrestrial vs. aquatic, C3 plants vs. C4 plants), otherwise the result would lead to a meaningless confounding effect (Haubrock et al. 2020b). The goodness of the similarity can be checked by testing whether the projected data falls into the community total hull area (Layman et al. 2007) after being standardized (Haubrock et al. 2019b).

Beside spatial, also temporal differences in species diet and relative abundance (e.g. insects boosts) and consequently in community structure must be considered when choosing data. This refers to natural seasonal changes but also to the time since introduction for already established populations, as the diet of a species can change during its invasion process (Tillberg et al. 2007), depending on resource availability (Ruffino et al. 2011).

Finally, it is well known that the carbon isotopic signature is depleted by some compounds, mostly lipids (Post et al. 2007). A plethora of methods such as lipid chemical extraction have been used to deal with this bias (Arostegui et al. 2019). Therefore, isotopic data from samples treated in the same way are needed, whereas untreated and lipid-extracted samples should not be compared, because this could lead to misinterpretations due to the incorrect topology of the projected data in the isotopic space.

Advantages

There are three main advantages that this predictive method can offer. First, the impact of a potentially introduced alien species on the native community in terms of predation can be estimated using mixing models (Parnell et al. 2013). Knowing the species composition of the host community, mixing models will allow to estimate which taxa could be mostly predated. If some of the mainly potentially predated taxa are of conservation concern, this will result in a high potential impact. On the other hand, if sensitive taxa are not likely to be heavily predated, this will reduce the risk associated with the potential introduction of a species.

Another important advantage is the estimation of feeding competition potentially occurring with other, already present, species. The overlapping resource use can be inferred by using models that investigate the proportion (Stasko et al. 2015) of potentially arising isotopic niche overlap (e.g. Bayesian or corrected standardized ellipse area or Kernel isotopic niche, Jackson et al. 2011; Eckrich et al. 2020). Isotopic niches are a multivariate (usually bidimensional) representation of the Hutchinson's n-dimensional ecological niche (Newsome et al. 2007). As discussed above, the niche defined by $\delta^{13}C$ and $\delta^{15}N$ reflects the trophic niche, so the degree of trophic niche overlap provides an index of potential competition between species. When niches are overlapped to some degree, competition is likely to occur, particularly when trophic resources become limiting (Pianka 1981).

Finally, hurdles for the reintroduction of native species as well as assisted migration projects can be identified and addressed a priori given the composition of the community where the reintroduction is planned (Haubrock et al. 2020b), informing the choice of most suitable sites where these actions will be most likely to succeed, minimizing the management costs and maximizing the success probability.

Assumptions

The most important assumption this approach relies on is the niche conservatism of the focal species. The trophic niche of a species in different ecosystems can vary (especially for generalist species) depending e.g. on the availability of different resources, community composition and habitat type (Balzani et al. 2021; Haubrock et al. 2021a,b) and ultimately on climate change (Bestion et al. 2019). Moreover, invasive species are known for their plasticity (Courant et al. 2017; Loureiro et al. 2019; Rolla et al. 2020), thus limiting the reliability of predictive modelling. Despite this, consistent patterns in feeding preferences of introduced populations have been well documented in some invasive species (Tillberg et al. 2007; Wilder et al. 2011). To address this issue, we suggest the use of data from other invasive populations, when available, as these can provide more reliable predictions (Barbet-Massin et al. 2018). However, these assumptions are the same as for other existing tools used in the prevention of potentially invasive species. Indeed, both predictive models and risk assessment protocols use information (e.g. behavioural or biological traits, impacts) on a species from its native or introduced ranges and project this information to predict potential impacts and geographic spread that could arise (Bacher et al. 2018; Roy et al. 2019; Liu et al. 2020).

Second, species should be at equilibrium in their new range and maintain their ecological niche (Gallien et al. 2012; Hattab et al. 2017). Moreover, the output is highly sensitive to uncertainties, errors, and deficient data (Katsanevakis and Moustakas 2018). Even the suggested species distribution model implementation using eDNA similarly presents some limits and potential biases (Muha et al. 2017). Alternative approaches have been proposed, such as comparative functional responses (Dick et al. 2017a,b), that showed predictive power across multiple study systems comprising different taxonomic groups and geographic regions (Cuthbert et al. 2019). Further, this approach allows the rapid assessment of ecological impacts, while incorporating context-dependencies such as warming (Haubrock et al. 2020c) and can be combined with field abundances and reproductive traits to scale-up and predict population-level impacts (Dick et al. 2017a; Dickey et al. 2020). However, the general applicability of this method to measure the impacts of a species remains debated (Dick et al. 2017c; Vonesh et al. 2017a, b). Nevertheless, these tools can provide good predictions, especially when data are derived from other invasive populations (e.g. Barbet-Massin et al. 2018).

True limitations are linked to stable isotope data availability, however with the increase in SIA studies, the available data are rapidly increasing, offering new opportunities. Pauli et al. (2015, 2017) have called for a global stable isotope database, which

would prove very useful in this context, together with open access publications and data repositories. If data are available, further information can be considered to refine the predictions. For instance, stable isotope data of a potential prey species could be partitioned according to size classes to improve the resolution of applied mixing models, and predators' diet, gape size or habitat use could be used as priors in Bayesian mixing models. Such a repository for isotopic data (IsoBank) has recently been launched (https://isobank.tacc.utexas.edu/), making feasible all the possibilities above discussed.

Application and potential outlook

With all the discussed potential insights provided by SIA-based risk assessments to improve management programmes, this approach potentially presents a unique way to inform practitioners in the fields of biological invasions and conservation biology to better inform stakeholders and governmental institutions. In practical terms, SIA-based risk assessments could be integrated in already existing tools such as EICAT and/or SEICAT as well as AS-ISK (Hawkins et al. 2015; Copp et al. 2016; Bacher et al. 2018), which have been widely adopted (also in combination, see Haubrock et al. 2021c), and new *ad hoc* tools can also be developed.

Other future developments could derive from this conceptually simple framework. For example, the availability of present and past environmental data, as well as future predictions (under climate change scenarios), integrated with SIA on museum samples will allow to include a temporal view on this approach, considerably improving its accuracy.

One interesting avenue that will surely show its potential in the invasion ecology field is the compound-specific stable isotope analysis (CS-SIA) of amino acids. In the context of our theoretic framework, this promising recent methodology will undoubtedly help in solving the issue of data standardisation and availability. This technique allows a more precise estimation of a consumer's trophic position based solely on the consumer's amino acid isotopic ratios (Chikaraishi et al. 2009). This releases the isotopic data from the need to be referenced by a correct baseline to be useful for projections. Indeed, the baseline presents potentially large spatial and temporal variations that are reflected in primary producers and, consequently, in upper trophic levels along the food web (Ishikawa 2018). CS-SIA makes the isotopic data from different populations directly comparable and increases the usable datasets (i.e. including those without baseline data available). Another advantage of CS-SIA is that different tissues do not present different isotopic signatures (e.g. Cherel et al. 2019), leading to an "absolute" isotopic signature of the animal. This also favours the usability and comparability of data from different tissues, without the need of utilising the same tissue. Further, CS-SIA on museum specimens can be used to reconstruct past food webs, helping in management and restoration efforts (Blanke et al. 2018). Although this technique is still costly, the decreasing costs of eDNA analysis suggest similar price reductions for the application of CS-SIA in the near future.

Conclusions

Projecting stable isotope data onto the isotopic space of the focal community has the potential to predict impacts accompanying a newly introduced species as well as the success of species reintroduction and assisted migration. Despite some required assumptions, the approach can have high utility from a scientific as well as management perspective by identifying trophic biological impacts of a wide range of taxonomic groups and habitats. Such results can thus be used to inform risk-based management programmes and make an important contribution to impact assessments, allowing a better prioritisation. Finally, optimising the chances of success of reintroduction as well as assisted migration efforts, will turn in a considerably better resource utilization.

Acknowledgements

The authors are grateful to Helen E. Roy for her helpful suggestions on an earlier version of this manuscript.

References

Ahmed DA, Hudgins EJ, Cuthbert RN, Haubrock PJ, Renault D, Bonnaud E, Diagne C, Courchamp F (2021a) Modelling the damage costs of invasive alien species. https://doi.org/10.21203/rs.3.rs-380351/v1

Ahmed DA, Hudgins EJ, Cuthbert RN, Kourantidou M, Diagne C, Haubrock PJ, Leung B, Liu C, Leroy B, Petrovskii S, Courchamp F (2021b) Managing biological invasions: the cost of inaction. Biological Invasions. https://doi.org/10.21203/rs.3.rs-300416/v1

Angulo E, Hoffmann B, Ballesteros-Mejia L, Taheri A, Balzani P, Renault D, Cordonnier M, Bellard C, Diagne C, Ahmed DA, Watari Y, Courchamp F (2021) Economic costs of invasive alien ants worldwide. Biological Invasions. https://doi.org/10.21203/rs.3.rs-346306/v1

Armstrong DP, Seddon PJ (2008) Directions in reintroduction biology. Trends in Ecology & Evolution 23(1): 20–25. https://doi.org/10.1016/j.tree.2007.10.003

Arostegui MC, Schindler DE, Holtgrieve GW (2019) Does lipid-correction introduce biases into isotopic mixing models? Implications for diet reconstruction studies. Oecologia 191(4): 745–755. https://doi.org/10.1007/s00442-019-04525-7

Bacher S, Blackburn TM, Essl F, Genovesi P, Heikkilä J, Jeschke JM, Jones G, Keller R, Kenis M, Kueffer C, Martinou AF, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Roy HE, Saul W-C, Scalera R, Vilà M, Wilson JRH, Kumschick S (2018) Socio-economic impact classification of alien taxa (SEICAT). Methods in Ecology and Evolution 9(1): 159–168. https://doi.org/10.1111/2041-210X.12844

Baker RHA, Black R, Copp GH, Haysom KA, Hulme PE, Thomas MB, Brown A, Brown M, Cannon RJC, Ellis J, Ellis M, Ferris R, Glaves P, Gozlan RE, Holt J, Howe L, Knight JD,

MacLeod A, Moore NP, Mumford JD, Murphy ST, Parrott D, Sansford CE, Smith GC, St-Hilaire S, Ward NL (2008) The UK risk assessment scheme for all alien species. In: Rabitsch W, Essl F, Klingensten F (Eds) Biological invasions from ecology to conservation. NeoBiota 7: 46–57.

Balzani P, Vizzini S, Santini G, Masoni A, Ciofi C, Ricevuto E, Chelazzi G (2016) Stable isotope analysis of trophic niche in two co-occurring native and invasive terrapins, *Emys orbicularis* and *Trachemys scripta elegans*. Biological Invasions, 18(12): 3611–3621. https://doi.org/10.1007/s10530-016-1251-x

Balzani P, Gozlan RE, Haubrock PJ (2020) Overlapping niches between two co-occurring invasive fish: the topmouth gudgeon *Pseudorasbora parva* and the common bleak *Alburnus alburnus*. Journal of Fish Biology 97(5): 1385–1392. https://doi.org/10.1111/jfb.14499

Balzani P, Vizzini S, Frizzi F, Masoni A, Lessard JP, Bernasconi C, Francoeur A, Ibarra-Isassi J, Brassard F, Cherix D, Santini G (2021) Plasticity in the trophic niche of an invasive ant explains establishment success and long-term coexistence. Oikos 130(5): 691–696. https://doi.org/10.1111/oik.08217

Barbet-Massin M, Rome Q, Villemant C, Courchamp F (2018) Can species distribution models really predict the expansion of invasive species? PLoS ONE 13(3): e0193085. https://doi.org/10.1371/journal.pone.0193085

Beaury EM, Fusco EJ, Jackson MR, Laginhas BB, Morelli TL, Allen JM, Pasquarella VJ, Bradley BA (2020) Incorporating climate change into invasive species management: insights from managers. Biological Invasions 22(2): 233–252. https://doi.org/10.1007/s10530-019-02087-6

Bestion E, Soriano-Redondo A, Cucherousset J, Jacob S, White J, Zinger L, Fourtune L, Di Gesu L, Teyssier A, Cote J (2019) Altered trophic interactions in warming climates: consequences for predator diet breadth and fitness. Proceedings of the Royal Society B 286(1914): e20192227. https://doi.org/10.1098/rspb.2019.2227

Bissattini AM, Haubrock PJ, Buono V, Balzani P, Borgianni N, Stellati L, Inghilesi AF, Tancioni L, Martinoli M, Tricarico E, Vignoli L (2021) Trophic structure of a pond community dominated by an invasive alien species: Insights from stomach content and stable isotope analyses. Aquatic Conservation: Marine and Freshwater Ecosystems 31(4): 948–963. https://doi.org/10.1002/aqc.3530

Blanke C, Chikaraishi Y, Vander Zanden MJ (2018) Historical niche partitioning and long-term trophic shifts in Laurentian Great Lakes deepwater coregonines. Ecosphere 9(1): e02080. https://doi.org/10.1002/aqc.3530

Bodey TW, Bearhop S, McDonald RA (2011) Invasions and stable isotope analysis–informing ecology and management. In: Veitch CR, Clout MN, Towns DR (Eds) Island invasives: eradication and management. IUCN, Gland, Switzerland: 148–151.

Boecklen WJ, Yarnes CT, Cook BA, James AC (2011) On the use of stable isotopes in trophic ecology. Annual Review of Ecology, Evolution, and Systematics 42: 411–440. https://doi.org/10.1146/annurev-ecolsys-102209-144726

Bond NR, Lake PS (2003) Local habitat restoration in streams: constraints on the effectiveness of restoration for stream biota. Ecological Management and Restoration 4(3): 193–198. https://doi.org/10.1046/j.1442-8903.2003.00156.x

Bradley BA, Laginhas BB, Whitlock R, Allen JM, Bates AE, Bernatchez G, Diez JM, Early R, Lenoir J, Vilà M, Sorte CJB (2019) Disentangling the abundance–impact relationship for invasive species. Proceedings of the National Academy of Sciences 116(20): 9919–9924. https://doi.org/10.1073/pnas.1818081116

Bradshaw CJ, Leroy B, Bellard C, Roiz D, Albert C, Fournier A, Barbet-Massin M, Salles JM, Simard F, Courchamp F (2016) Massive yet grossly underestimated global costs of invasive insects. Nature Communications 7(1): 1–8. https://doi.org/10.1038/ncomms12986

Brunel S, Branquart E, Fried G, Van Valkenburg J, Brundu G, Starfinger U, Buholzer S, Uludag A, Joseffson M, Baker R (2010) The EPPO prioritization process for invasive alien plants. EPPO bulletin 40(3): 407–422. https://doi.org/10.1111/j.1365-2338.2010.02423.x

Chai SL, Zhang J, Nixon A, Nielsen S (2016) Using risk assessment and habitat suitability models to prioritise invasive species for management in a changing climate. PLoS ONE 11(10): e0165292. https://doi.org/10.1371/journal.pone.0165292

Chapman D, Pescott OL, Roy HE, Tanner R (2019) Improving species distribution models for invasive non-native species with biologically informed pseudo-absence selection. Journal of Biogeography 46(5): 1029–1040. https://doi.org/10.1111/jbi.13555

Cherel Y, Bustamante P, Richard P (2019) Amino acid $\delta^{13}C$ and $\delta^{15}N$ from sclerotized beaks: a new tool to investigate the foraging ecology of cephalopods, including giant and colossal squids. Marine Ecology Progress Series 624: 89–102. https://doi.org/10.3354/meps13002

Chikaraishi Y, Ogawa NO, Kashiyama Y, Takano Y, Suga H, Tomitani A, Miyashita H, Kitazato H, Ohkouchi N (2009) Determination of aquatic food-web structure based on compound-specific nitrogen isotopic composition of amino acids. Limnology and Oceanography: methods 7(11): 740–750. https://doi.org/10.4319/lom.2009.7.740

Cochran-Biederman JL, Wyman KE, French WE, Loppnow GL (2015) Identifying correlates of success and failure of native freshwater fish reintroductions. Conservation Biology 29(1): 175–186. https://doi.org/10.1111/cobi.12374

Copp GH, Vilizzi L, Mumford J, Fenwick GV, Godard MJ, Gozlan RE (2009) Calibration of FISK, an invasiveness screening tool for nonnative freshwater fishes. Risk Analysis: An International Journal 29(3): 457–467. https://doi.org/10.1111/j.1539-6924.2008.01159.x

Copp GH, Vilizzi L, Tidbury H, Stebbing PD, Tarkan AS, Miossec L, Goulletquer P (2016) Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK. Management of Biological Invasions 7(4): 343–350. https://doi.org/10.3391/mbi.2016.7.4.04

Courant J, Vogt S, Marques R, Measey J, Secondi J, Rebelo R, De Villiers A, Ihlow F, De Busschere C, Backeljau T, Rödder D, Herrel A (2017) Are invasive populations characterized by a broader diet than native populations? PeerJ 5: e3250. https://doi.org/10.7717/peerj.3250

Crooks JA, Chang AL, Ruiz GM (2011) Aquatic pollution increases the relative success of invasive species. Biological Invasions 13(1): 165–176. https://doi.org/10.1007/s10530-010-9799-3

Cuthbert RN, Dickey JW, Coughlan NE, Joyce PW, Dick JT (2019) The Functional Response Ratio (FRR): advancing comparative metrics for predicting the ecological impacts of invasive alien species. Biological Invasions 21(8): 2543–2547. https://doi.org/10.1007/s10530-019-02002-z

Dahlstrom A, Hewitt CL, Campbell ML (2011) A review of international, regional and national biosecurity risk assessment frameworks. Marine Policy 35(2): 208–217. https://doi.org/10.1016/j.marpol.2010.10.001

Davidson AD, Hewitt CL (2014) How often are invasion-induced ecological impacts missed? Biological Invasions 16(5): 1165–1173. https://doi.org/10.1007/s10530-013-0570-4

Davidson A, Fusaro A, Sturtevant RA, Kashian DR (2017) Development of a risk assessment framework to predict invasive species establishment for multiple taxonomic groups and vectors of introduction. Management of Biological Invasions 8(1): 25–36. https://doi.org/10.3391/mbi.2017.8.1.03

Diagne C, Leroy B, Vaissière AC, Gozlan RE, Roiz D, Jarić I, Salles J-M, Bradshaw CJA, Courchamp F (2021) High and rising economic costs of biological invasions worldwide. Nature 592(7855): 571–576. https://doi.org/10.1038/s41586-021-03405-6

Dick JT, Laverty C, Lennon JJ, Barrios-O'Neill D, Mensink PJ, Britton JR, Médoc V, Boets P, Alexander ME, Taylor NG, Dunn AM, Hatcher MJ, Rosewarne PJ, Crookes S, MacIsaac HJ, Xu M, Ricciardi A, Wasserman RJ, Ellender BR, Weyl OLF, Lucy FE, Banks PB, Dodd JA, MacNeil C, Penk MR, Aldridge DC, Caffrey JM (2017a) Invader Relative Impact Potential: a new metric to understand and predict the ecological impacts of existing, emerging and future invasive alien species. Journal of Applied Ecology 54(4): 1259–1267. https://doi.org/10.1111/1365-2664.12849

Dick JT, Alexander ME, Ricciardi A, Laverty C, Downey PO, Xu M, Jeschke JM, Saul W-C, Hill MP, Wasserman R, Barrios-O'Neill D, Weyl OLF, Shaw RH (2017b) Functional responses can unify invasion ecology. Biological Invasions 19(5): 1667–1672. https://doi.org/10.1007/s10530-016-1355-3

Dick JT, Alexander ME, Ricciardi A, Laverty C, Downey PO, Xu M, Jeschke JM, Saul W-C, Hill MP, Wasserman R, Barrios-O'Neill D, Weyl OLF, Shaw RH (2017c) Fictional responses from Vonesh et al. Biological Invasions 19(5): 1677–1678. https://doi.org/10.1007/s10530-016-1360-6

Dickey JW, Cuthbert RN, South J, Britton JR, Caffrey J, Chang X, Crane K, Coughlan N, Fadaei E, Farnsworth K, Ismar-Rebitz S, Julius M, Laverty C, Lucy FE, MacIsaac HJ, McCard M, McGlade C, Reid N, Ricciardi A, Wasserman RJ, Dick JT (2020) On the RIP: using Relative Impact Potential to assess the ecological impacts of invasive alien species. NeoBiota 55: 27–60. https://doi.org/10.3897/neobiota.55.49547

Doherty TS, Glen AS, Nimmo DG, Ritchie EG, Dickman CR (2016) Invasive predators and global biodiversity loss. Proceedings of the National Academy of Sciences 113(40): 11261–11265. https://doi.org/10.1073/pnas.1602480113

Dörner H, Benndorf J (2003) Piscivory by large eels on young-of-the-year fishes: its potential as a biomanipulation tool. Journal of Fish Biology 62(2): 491–494. https://doi.org/10.1046/j.1095-8649.2003.00035.x

Eckrich CA, Albeke SE, Flaherty EA, Bowyer RT, Ben-David M (2020) rKIN: Kernel-based method for estimating iso topic niche size and overlap. Journal of Animal Ecology 89: 757–771. https://doi.org/10.1111/1365-2656.13159

Ehrenfeld JG (2010) Ecosystem consequences of biological invasions. Annual review of ecology, evolution, and systematics 41: 59–80. https://doi.org/10.1146/annurev-ecolsys-102209-144650

Essl F, Nehring S, Klingenstein F, Milasowszky N, Nowack C, Rabitsch W (2011) Review of risk assessment systems of IAS in Europe and introducing the German–Austrian Black List Information System (GABLIS). Journal for Nature Conservation 19(6): 339–350. https://doi.org/10.1016/j.jnc.2011.08.005

Fournier A, Penone C, Pennino MG, Courchamp F (2019) Predicting future invaders and future invasions. Proceedings of the National Academy of Sciences 116(16): 7905–7910. https://doi.org/10.1073/pnas.1803456116

Fry B (2006) Stable isotope ecology. Springer, Berlin. https://doi.org/10.1007/0-387-33745-8

Gaiotto JV, Abrahão CR, Dias RA, Bugoni L (2020) Diet of invasive cats, rats and tegu lizards reveals impact over threatened species in a tropical island. Perspectives in Ecology and Conservation 18(4): 294–303. https://doi.org/10.1016/j.pecon.2020.09.005

Gallien L, Douzet R, Pratte S, Zimmermann NE, Thuiller W (2012) Invasive species distribution models–how violating the equilibrium assumption can create new insights. Global Ecology and Biogeography 21(11): 1126–1136. https://doi.org/10.1111/j.1466-8238.2012.00768.x

Gergs R, Koester M, Schulz RS, Schulz R (2014) Potential alteration of cross-ecosystem resource subsidies by an invasive aquatic macroinvertebrate: implications for the terrestrial food web. Freshwater Biology 59(12): 2645–2655. https://doi.org/10.1111/fwb.12463

Gollasch S, Leppäkoski E (2007) Risk assessment and management scenarios for ballast water mediated species introductions into the Baltic Sea. Aquatic Invasions 2(4): 313–340. https://doi.org/10.3391/ai.2007.2.4.3

Haase P, Pilotto F (2019) A method for the reintroduction of entire benthic invertebrate communities in formerly degraded streams. Limnologica 77: e125689. https://doi.org/10.1016/j.limno.2019.125689

Hällfors MH, Aikio S, Schulman LE (2017) Quantifying the need and potential of assisted migration. Biological Conservation 205: 34–41. https://doi.org/10.1016/j.biocon.2016.11.023

Hattab T, Garzón-López CX, Ewald M, Skowronek S, Aerts R, Horen H, Brasseur B, Gallet-Moron E, Spicher F, Decocq G, Feilhauer H, Honnay O, Kempeneers P, Schmidtlein S, Somers B, Van De Kerchove R, Rocchini D, Lenoir J (2017) A unified framework to model the potential and realized distributions of invasive species within the invaded range. Diversity and Distributions 23(7): 806–819. https://doi.org/10.1111/ddi.12566

Haubrock PJ, Criado A, Monteoliva AP, Monteoliva JA, Santiago T, Inghilesi AF, Tricarico E (2018) Control and eradication efforts of aquatic alien fish species in Lake Caicedo Yuso-Arreo. Management of Biological Invasions 9(3): 267–278. https://doi.org/10.3391/mbi.2018.9.3.09

Haubrock PJ, Balzani P, Azzini M, Inghilesi AF, Veselý L, Guo W, Tricarico E (2019a). Shared histories of co-evolution may affect trophic interactions in a freshwater community dominated by alien species. Frontiers in Ecology and Evolution 7: e355. https://doi.org/10.3389/fevo.2019.00355

Haubrock PJ, Balzani P, Criado A, Inghilesi AF, Tricarico E, Monteoliva AP (2019b) Predicting the effects of reintroducing a native predator (European eel, *Anguilla anguilla*) into a freshwater community dominated by alien species using a multidisciplinary approach. Management of Biological Invasions 10(1): 171–191. https://doi.org/10.3391/mbi.2019.10.1.11

Haubrock PJ, Azzini M, Balzani P, Inghilesi AF, Tricarico E (2020a) When alien catfish meet—Resource overlap between the North American *Ictalurus punctatus* and immature European *Silurus glanis* in the Arno River (Italy). Ecology of Freshwater Fish 29(1): 4–17. https://doi.org/10.1111/eff.12481

Haubrock PJ, Balzani P, Britton JR, Haase P (2020b) Using stable isotopes to analyse extinction risks and reintroduction opportunities of native species in invaded ecosystems. Scientific Reports 10(1): 1–11. https://doi.org/10.1038/s41598-020-78328-9

Haubrock PJ, Cuthbert RN, Veselý L, Balzani P, Baker NJ, Dick JT, Kouba A (2020c) Predatory functional responses under increasing temperatures of two life stages of an invasive gecko. Scientific Reports 10(1): 1–10. https://doi.org/10.1038/s41598-020-67194-0

Haubrock PJ, Balzani P, Hundertmark I, Cuthbert RN (2021a) Spatial and size variation in dietary niche of a non-native freshwater fish. Ichthyology & Herpetology 109(2): 501–506. https://doi.org/10.1643/i2020099

Haubrock PJ, Balzani P, Matsuzaki SIS, Tarkan AS, Kourantidou M, Haase P (2021b) Spatio-temporal niche plasticity of a freshwater invader as a harbinger of impact variability. Science of The Total Environment 777: e145947. https://doi.org/10.1016/j.scitotenv.2021.145947

Haubrock PJ, Copp GH, Johović I, Balzani P, Inghilesi AF, Nocita A, Tricarico E (2021c) North American channel catfish, *Ictalurus punctatus*: a neglected but potentially invasive freshwater fish species?. Biological Invasions 23(5): 1563–1576. https://doi.org/10.1007/s10530-021-02459-x

Hawkins CL, Bacher S, Essl F, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Nentwig, Pergl J, Pyšek P, Rabitsch W, Richardson DM, Vilà M, Wilson JRU, Genovesi P, Blackburn TM (2015) Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). Diversity and Distributions 21(11): 1360–1363. https://doi.org/10.1111/ddi.12379

Hellmann JJ, Byers JE, Bierwagen BG, Dukes JS (2008) Five potential consequences of climate change for invasive species. Conservation Biology 22(3): 534–543. https://doi.org/10.1111/j.1523-1739.2008.00951.x

Hoegh-Guldberg O, Hughes L, McIntyre S, Lindenmayer DB, Parmesan C, Possingham HP, Thomas CD (2008) Ecology. Assisted colonization and rapid climate change. Science 321(5887): 345–346. https://doi.org/10.1126/science.1157897

Howeth JG, Gantz CA, Angermeier PL, Frimpong EA, Hoff MH, Keller RP, Mandrak NE, Marchetti MP, Olden JD, Romagosa CM, Lodge DM (2016) Predicting invasiveness of species in trade: climate match, trophic guild and fecundity influence establishment and impact of non-native freshwater fishes. Diversity and Distributions 22(2): 148–160. https://doi.org/10.1111/ddi.12391

Ishikawa NF (2018) Use of compound-specific nitrogen isotope analysis of amino acids in trophic ecology: assumptions, applications, and implications. Ecological Research 33(5): 825–837. https://doi.org/10.1007/s11284-018-1616-y

Jackson AL, Inger R, Parnell AC, Bearhop S (2011) Comparing isotopic niche widths among and within communities: SIBER–Stable Isotope Bayesian Ellipses in R. Journal of Animal Ecology 80(3): 595–602. https://doi.org/10.1111/j.1365-2656.2011.01806.x

Jourdan J, Plath M, Tonkin JD, Ceylan M, Dumeier AC, Gellert G, Graf W, Hawkins CP, Kiel E, Lorenz AW, Matthaei CD, Verdonschot PFM, Verdonschot RCM, Haase P (2019) Reintroduction of freshwater macroinvertebrates: challenges and opportunities. Biological Reviews 94(2): 368–387. https://doi.org/10.1111/brv.12458

Juarez-Sanchez D, Blake JG, Hellgren EC (2019) Variation in Neotropical river otter (*Lontra longicaudis*) diet: Effects of an invasive prey species. PLoS ONE 14(10): e0217727. https://doi.org/10.1371/journal.pone.0217727

Kail J, Arle J, Jähnig SC (2012) Limiting factors and thresholds for macroinvertebrate assemblages in European rivers: empirical evidence from three datasets on water quality, catchment urbanization, and river restoration. Ecological Indicators 18: 63–72. https://doi.org/10.1016/j.ecolind.2011.09.038

Katsanevakis S, Moustakas A (2018) Uncertainty in marine invasion science. Frontiers in Marine Science 5: e38. https://doi.org/10.3389/fmars.2018.00038

Kelly JF (2000) Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. Canadian Journal of Zoology 78(1): 1–27. https://doi.org/10.1139/z99-165

Kumschick S, Bacher S, Bertolino S, Blackburn TM, Evans T, Roy HE, Smith K (2020) Appropriate uses of EICAT protocol, data and classifications. NeoBiota 62: 193–212. https://doi.org/10.3897/neobiota.62.51574

Layman CA, Arrington DA, Montaña CG, Post DM (2007) Can stable isotope ratios provide for community-wide measures of trophic structure? Ecology 88(1): 42–48. https://doi.org/10.1890/0012-9658(2007)88[42:CSIRPF]2.0.CO;2

Layman CA, Araujo MS, Boucek R, Hammerschlag-Peyer CM, Harrison E, Jud ZR, Matich P, Rosenblatt AE, Vaudo JJ, Yeager LA, Post DM, Bearhop S (2012) Applying stable isotopes to examine food-web structure: an overview of analytical tools. Biological Reviews 87(3): 545–562. https://doi.org/10.1111/j.1469-185X.2011.00208.x

Lehmann D, Mfune JKE, Gewers E, Cloete J, Brain C, Voigt CC (2013) Dietary plasticity of generalist and specialist ungulates in the Namibian desert: a stable isotopes approach. PLoS ONE 8(8): e72190. https://doi.org/10.1371/journal.pone.0072190

Leibold MA, Chase JM, Shurin JB, Downing AL (1997) Species turnover and the regulation of trophic structure. Annual Review of Ecology and Systematics 28(1): 467–494. https://doi.org/10.1146/annurev.ecolsys.28.1.467

Leidenberger S, Obst M, Kulawik R, Stelzer K, Heyer K, Hardisty A, Bourlat SJ (2015) Evaluating the potential of ecological niche modelling as a component in marine non-indigenous species risk assessments. Marine Pollution Bulletin 97(1–2): 470–487. https://doi.org/10.1016/j.marpolbul.2015.04.033

Liu C, Wolter C, Xian W, Jeschke JM (2020) Most invasive species largely conserve their climatic niche. Proceedings of the National Academy of Sciences 117(38): 23643–23651. https://doi.org/10.1073/pnas.2004289117

Loch JM, Walters LJ, Cook GS (2020) Recovering trophic structure through habitat restoration: A review. Food Webs 25: e00162. https://doi.org/10.1016/j.fooweb.2020.e00162

Loureiro TG, Anastácio PM, de Siqueira Bueno SL, Woodd CT, Araujod PB (2019). Food matters: Trophodynamics and the role of diet in the invasion success of *Procambarus clarkii* in

an Atlantic Forest conservation area. Limnologica 79: e125717. https://doi.org/10.1016/j.limno.2019.125717

Mainali KP, Warren DL, Dhileepan K, McConnachie A, Strathie L, Hassan G, Karki D, Shrestha BB, Parmesan C (2015) Projecting future expansion of invasive species: comparing and improving methodologies for species distribution modeling. Global Change Biology 21(12): 4464–4480. https://doi.org/10.1111/gcb.13038

Marchetti MP, Engstrom T (2016) The conservation paradox of endangered and invasive species. Conservation Biology 30(2): 434–437. https://doi.org/10.1111/cobi.12642

Marková J, Jerikho R, Wardiatno Y, Kamal MM, Magalhães ALB, Bohatá L, Kalous L, Patoka J (2020) Conservation paradox of giant arapaima *Arapaima gigas* (Schinz, 1822)(Pisces: Arapaimidae): endangered in its native range in Brazil and invasive in Indonesia. Knowledge & Management of Aquatic Ecosystems 421: e47. https://doi.org/10.1051/kmae/2020039

Mavraki N, De Mesel I, Degraer S, Moens T, Vanaverbeke J (2020) Resource niches of co-occurring invertebrate species at an offshore wind turbine indicate a substantial degree of trophic plasticity. Frontiers in Marine Science 7: 379. https://doi.org/10.3389/fmars.2020.00379

Mazza G, Tricarico E [Eds] (2018) Invasive species and human health (Vol. 10). CABI. https://doi.org/10.1079/9781786390981.0000

McCue MD, Javal M, Clusella-Trullas S, Le Roux JJ, Jackson MC, Ellis AG, Richardson DM, Valentine AJ, Terblanche JS (2020) Using stable isotope analysis to answer fundamental questions in invasion ecology: Progress and prospects. Methods in Ecology and Evolution 11(2): 196–214. https://doi.org/10.1111/2041-210X.13327

McGeoch MA, Genovesi P, Bellingham PJ, Costello MJ, McGrannachan C, Sheppard A (2016) Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. Biological Invasions 18(2): 299–314. https://doi.org/10.1007/s10530-015-1013-1

McMahon KW, McCarthy MD (2016) Embracing variability in amino acid $\delta^{15}N$ fractionation: mechanisms, implications, and applications for trophic ecology. Ecosphere 7(12): e01511. https://doi.org/10.1002/ecs2.1511

Middelburg JJ (2014) Stable isotopes dissect aquatic food webs from the top to the bottom. Biogeosciences 11(8): 2357–2371. https://doi.org/10.5194/bg-11-2357-2014

Muha TP, Rodríguez-Rey M, Rolla M, Tricarico E (2017) Using environmental DNA to improve species distribution models for freshwater invaders. Frontiers in Ecology and Evolution 5: e158. https://doi.org/10.3389/fevo.2017.00158

Newsome SD, Martinez del Rio C, Bearhop S, Phillips DL (2007) A niche for isotopic ecology. Frontiers in Ecology and the Environment 5(8): 429–436. https://doi.org/10.1890/060150.1

Oe S, Sashika M, Fujimoto A, Shimozuru M, Tsubota T (2020) Predation impacts of invasive raccoons on rare native species. Scientific reports 10(1): 1–12. https://doi.org/10.1038/s41598-020-77016-y

Parnell AC, Phillips DL, Bearhop S, Semmens BX, Ward EJ, Moore JW, Jackson AL, Grey J, Kelly DJ, Inger R (2013) Bayesian stable isotope mixing models. Environmetrics 24(6): 387–399. https://doi.org/10.1002/env.2221

Pauli JN, Steffan SA, Newsome SD (2015) It is time for IsoBank. BioScience 65(3): 229–230. https://doi.org/10.1093/biosci/biu230

Pauli JN, Newsome SD, Cook JA, Harrod C, Steffan SA, Baker CJ, Ben-David M, Bloom D, Bowen GJ, Cerling TE, Cicero C, Cook C, Dohm M, Dharampal PS, Graves G, Gropp R, Hobson KA, Jordan C, MacFadden B, Birch SP, Poelen J, Ratnasingham S, Russell L, Stricker CA, Uhen MD, Yarnes CT, Hayden B (2017) Opinion: Why we need a centralized repository for isotopic data. Proceedings of the National Academy of Sciences 114(12): 2997–3001. https://doi.org/10.1073/pnas.1701742114

Pérez I, Anadón JD, Díaz M, Nicola GG, Tella JL, Giménez A (2012) What is wrong with current translocations? A review and a decision-making proposal. Frontiers in Ecology and the Environment 10(9): 494–501. https://doi.org/10.1890/110175

Peterson K, Bode M (2021) Using ensemble modeling to predict the impacts of assisted migration on recipient ecosystems. Conservation Biology 35(2): 678–687. https://doi.org/10.1111/cobi.13571

Phillips DL, Inger R, Bearhop S, Jackson AL, Moore JW, Parnell AC, Semmens BX, Ward EJ (2014) Best practices for use of stable isotope mixing models in food-web studies. Canadian Journal of Zoology 92(10): 823–835. https://doi.org/10.1139/cjz-2014-0127

Pianka ER (1981) Competition and niche theory. In: May RM (Ed) Theoretical ecology: principles and applications. Blackwell, Oxford, 167–196.

Post DM (2002) Using stable isotopes to estimate trophic position: Models, methods, and assumptions. Ecology 83(3): 703–718. https://doi.org/10.1890/0012-9658(2002)083[0703:USITET]2.0.CO;2

Post DM, Layman CA, Arrington DA, Takimoto G, Quattrochi J, Montana CG (2007) Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses. Oecologia 152: 179–189. https://doi.org/10.1007/s00442-006-0630-x

Quezada-Romegialli C, Jackson AL, Hayden B, Kahilainen KK, Lopes C, Harrod C (2018) tRophicPosition, an R package for the Bayesian estimation of trophic position from consumer stable isotope ratios. Methods in Ecology and Evolution 9(6): 1592–1599. https://doi.org/10.1111/2041-210X.13009

Rahel FJ, Olden JD (2008) Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22(3): 521–533. https://doi.org/10.1111/j.1523-1739.2008.00950.x

Ricciardi A, Blackburn TM, Carlton JT, Dick JT, Hulme PE, Iacarella JC, Jeschke JM, Liebhold AM, Lockwood JL, MacIsaac HJ, Pyšek P, Richardson DM, Ruiz GM, Simberloff D, Sutherland WJ, Wardle DA, Aldridge DC (2017) Invasion science: a horizon scan of emerging challenges and opportunities. Trends in Ecology & Evolution 32(6): 464–474. https://doi.org/10.1016/j.tree.2017.03.007

Richardson DM, Hellmann JJ, McLachlan JS, Sax DF, Schwartz MW, Gonzalez P, Brennan EJ, Camacho A, Root TL, Sala OE, Schneider SH, Ashe DM, Rappaport Clark J, Early R, Etterson JR, Fielder ED, Gill JL, Minteer BA, Polasky S, Safford HD, Thompson AR, Vellend M (2009) Multidimensional evaluation of managed relocation. Proceedings of the National Academy of Sciences 106(24): 9721–9724. https://doi.org/10.1073/pnas.0902327106

Rolla M, Consuegra S, Garcia de Leaniz C (2020) Trophic plasticity of the highly invasive topmouth gudgeon (*Pseudorasbora parva*) inferred from stable isotope analysis. Frontiers in Ecology and Evolution 8: e212. https://doi.org/10.3389/fevo.2020.00212

Roni P, Åberg U, Weber C (2018) A review of approaches for monitoring the effectiveness of regional river habitat restoration programs. North American Journal of Fisheries Management 38(5): 1170–1186. https://doi.org/10.1002/nafm.10222

Roy HE, Bacher S, Essl F, Adriaens T, Aldridge DC, Bishop JD, Blackburn TM, Branquart E, Brodie J, Carboneras C, Cottier-Cook EJ, Copp GH, Dean HJ, Eilenberg J, Gallardo B, Garcia M, García-Berthou E, Genovesi P, Hulme PE, Kenis M, Kerckhof F, Kettunen M, Minchin D, Nentwig W, Nieto A, Pergl J, Pescott OL, Peyton JM, Preda C, Roques A, Rorke SL, Scalera R, Schindler S, Schönrogge K, Sewell J, Solarz W, Stewart AJA, Tricarico E, Vanderhoeven S, van der Velde G, Vilà M, Wood CA, Zenetos A, Rabitsch W (2019) Developing a list of invasive alien species likely to threaten biodiversity and ecosystems in the European Union. Global Change Biology 25(3): 1032–1048. https://doi.org/10.1111/gcb.14527

Ruffino L, Russell JC, Pisanu B, Caut S, Vidal E (2011) Low individual-level dietary plasticity in an island-invasive generalist forager. Population Ecology 53(4): 535–548. https://doi.org/10.1007/s10144-011-0265-6

Schwartz MW, Hellmann JJ, McLachlan JM, Sax DF, Borevitz JO, Brennan J, Camacho AE, Ceballos G, Clark JR, Doremus H, Early R, Etterson JR, Fielder D, Gill JL, Gonzalez P, Green N, Hannah L, Jamieson DW, Javeline D, Minteer BA, Odenbaugh J, Polasky S, Richardson DM, Root TL, Safford HD, Sala O, Schneider SH, Thompson AR, Williams JW, Vellend M, Vitt P, Zellmer S (2012) Managed relocation: integrating the scientific, regulatory, and ethical challenges. BioScience 62(8): 732–743. https://doi.org/10.1525/bio.2012.62.8.6

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nature Communications 8(1): 1–9. https://doi.org/10.1038/ncomms14435

Simberloff D, Von Holle B (1999) Positive interactions of nonindigenous species: invasional meltdown? Biological Invasions 1(1): 21–32. https://doi.org/10.1023/A:1010086329619

Simberloff D, Martin JL, Genovesi P, Maris V, Wardle DA, Aronson J, Courchamp F, Galil B, García-Berthou E, Pascal M, Pyšek P, Sousa R, Tabacchi E, Vilà M (2013) Impacts of biological invasions: what's what and the way forward. Trends in Ecology & Evolution 28(1): 58–66. https://doi.org/10.1016/j.tree.2012.07.013

Srėbalienė G, Olenin S, Minchin D, Narščius A (2019) A comparison of impact and risk assessment methods based on the IMO Guidelines and EU invasive alien species risk assessment frameworks. PeerJ 7: e6965. https://doi.org/10.7717/peerj.6965

Stasko AD, Johnston TA, Gunn JM (2015) Effects of water clarity and other environmental factors on trophic niches of two sympatric piscivores. Freshwater Biology 60(7): 1459–1474. https://doi.org/10.1111/fwb.12581

Stellati L, Borgianni N, Bissattini AM, Buono V, Haubrock PJ, Balzani P, Tricarico E, Inghilesi AF, Tancioni L, Martinoli M, Luiselli L, Vignoli L (2019) Living with aliens: suboptimal

ecological condition in semiaquatic snakes inhabiting a hot spot of allodiversity. Acta Oecologica 100: e103466. https://doi.org/10.1016/j.actao.2019.103466

Svanbäck R, Quevedo M, Olsson J, Eklöv P (2015) Individuals in food webs: the relationships between trophic position, omnivory and among-individual diet variation. Oecologia 178(1): 103–114. https://doi.org/10.1007/s00442-014-3203-4

Tillberg CV, Holway DA, LeBrun EG, Suarez AV (2007) Trophic ecology of invasive Argentine ants in their native and introduced ranges. Proceedings of the National Academy of Sciences 104(52): 20856–20861. https://doi.org/10.1073/pnas.0706903105

Uden DR, Allen CR, Angeler DG, Corral L, Fricke KA (2015) Adaptive invasive species distribution models: a framework for modeling incipient invasions. Biological Invasions 17(10): 2831–2850. https://doi.org/10.1007/s10530-015-0914-3

Vander Zanden MJ, Casselman JM, Rasmussen JB (1999) Stable isotope evidence for the food web consequences of species invasions in lakes. Nature 401(6752): 464–467. https://doi.org/10.1038/46762

Vanderklift MA, Ponsard S (2003) Sources of variation in consumer-diet $\delta^{15}N$ enrichment: a meta-analysis. Oecologia 136(2): 169–182. https://doi.org/10.1007/s00442-003-1270-z

Veselý L, Ruokonen TJ, Weiperth A, Kubec J, Szajbert B, Guo W, Ercoli F, Bláha M, Buřič M, Hämäläinen H, Kouba A (2021) Trophic niches of three sympatric invasive crayfish of EU concern. Hydrobiologia 848(3): 727–737. https://doi.org/10.1007/s10750-020-04479-5

Vilizzi L, Copp GH, Hill JE, Adamovich B, Aislabie L, Akin D, Al-Faisalh AJ, Almeida D, Azmai MNA, Bakiu R, Bellati A, Bernier R, Bies JM, Bilge G, Branco P, Bui TD, Canning-Clode J, Ramos HAC, Castellanos-Galindo GA, Castro N, Chaichana R, Chainho P, Chan J, Cunico AM, Curd A, Dangchana P, Dashinov D, Davison PI, de Camargo MP, Dodd JA, Durland Donahou AL, Edsman L, Ekmekçi FG, Elphinstone-Davis J, Erős T, Evangelista C, Fenwick G, Ferincz A, Ferreira T, Feunteun E, Filiz H, Forneck SC, Gajduchenko HS, Monteiro JG, Gestoso I, Giannetto D, Gilles Jr AS, Gizzi F, Glamuzina B, Glamuzina L, Goldsmit J, Gollasch S, Goulletquer P, Grabowska J, Harmer R, Haubrock PJ, He D, Hean JW, Herczeg G, Howland KL, İlhan A, Interesova E, Jakubčinová K, Jelmert A, Johnsen SI, Kakareko T, Kanongdate K, Killi N, Kim J-E, Kırankaya SG, Kňazovická D, Kopecký O, Kostov V, Koutsikos N, Kozic S, Kuljanishvili T, Kumar B, Kumar L, Kurita Y, Kurtul I, Lazzaro L, Lee L, Lehtiniemi M, Leonardi G, Leuven RSEW, Li S, Lipinskaya T, Liu F, Lloyd L, Lorenzoni M, Luna SA, Lyons TJ, Magellan K, Malmstrøm M, Marchini A, Marr SM, Masson G, Masson L, McKenzie CH, Memedemin D, Mendoza R, Minchin D, Miossec L, Moghaddas SD, Moshobane MC, Mumladze L, Naddafi R, Najafi-Majd E, Năstase A, Năvodaru I, Neal JW, Nienhuis S, Nimtim M, Nolan ET, Occhipinti-Ambrogi A, Ojaveer H, Olenin S, Olsson K, Onikura N, O'Shaughnessy K, Paganelli D, Parretti P, Patoka J, Pavia Jr RTB, Pellitteri-Rosa D, Pelletier-Rousseau M, Peralta EM, Perdikaris C, Pietraszewski D, Piria M, Pitois S, Pompei L, Poulet N, Preda C, Puntila-Dodd R, Qashqaei AT, Radočaj T, Rahmani H, Raj S, Reeves D, Ristovska M, Rizevsky V, Robertson DR, Robertson P, Ruykys L, Saba AO, Santos JM, Sarı HM; Segurado P, Semenchenko V, Senanan W, Simard N, Simonović P, Skóra ME, Švolíková KS, Smeti E, Šmídová T, Špelić I, Srėbalienė G, Stasolla G, Stebbing P, Ševove B, Suresh VR, Szajbertb B, Ta KAT, Tarkan AS, Tempesti J, Therriault TW, Tidbury HJ, Top-Karakuş N, Tricarico E, Troca

DFA, Tsiamis K, Tuckett QM, Tutman P, Uyan U, Uzunova E, Vardakas L, Velle G, Verreycken H, Vintsek L, Wei H, Weiperth A, Weyl OLF, Winter ER, Włodarczyk R, Wood LE, Yang R, Yapıcı S, Yeo SSB, Yoğurtçuoğlu B, Yunnie ALE, Zhu Y, Zięba G, Žitňanová K, Clarke S (2021) A global-scale screening of non-native aquatic organisms to identify potentially invasive species under current and future climate conditions. Science of the Total Environment 788: e147868. https://doi.org/10.1016/j.scitotenv.2021.147868

Vonesh J, McCoy M, Altwegg R, Landi P, Measey J (2017a) Functional responses can't unify invasion ecology. Biological Invasions 19(5): 1673–1676. https://doi.org/10.1007/s10530-016-1356-2

Vonesh J, McCoy M, Altwegg R, Landi P, Measey J (2017b) Rather than unifying invasion biology, Dick et al.'s approach rests on subjective foundations. Biological Invasions 19(5): 1679–1680. https://doi.org/10.1007/s10530-016-1361-5

Walsh JR, Carpenter SR, Vander Zanden MJ (2016) Invasive species triggers a massive loss of ecosystem services through a trophic cascade. Proceedings of the National Academy of Sciences 113(15): 4081–4085. https://doi.org/10.1073/pnas.1600366113

Wilder SM, Holway DA, Suarez AV, LeBrun EG, Eubanks MD (2011) Intercontinental differences in resource use reveal the importance of mutualisms in fire ant invasions. Proceedings of the National Academy of Sciences 108(51): 20639–20644. https://doi.org/10.1073/pnas.1115263108

Willis SG, Hill JK, Thomas CD, Roy DB, Fox R, Blakeley DS, Huntley B (2009) Assisted colonization in a changing climate: a test-study using two UK butterflies. Conservation Letters 2(1): 46–52. https://doi.org/10.1111/j.1755-263X.2008.00043.x

Yoğurtçuoğlu B, Bucak T, Ekmekçi FG, Kaya C, Tarkan AS (2021) Mapping the Establishment and Invasiveness Potential of Rainbow Trout (*Oncorhynchus mykiss*) in Turkey: With Special Emphasis on the Conservation of Native Salmonids. Frontiers in Ecology and Evolution 8: 599881. https://doi.org/10.3389/fevo.2020.599881.